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INVESTIGATION OF AN INFLATABLE DECELERATOR ATTACHED TO A 120-DEG CONICAL ENTRY CAPSULE AT MACH NUMBERS FROM 2.55 TO 4.40

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ARO, Inc.

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PROPULSION WIND TUNNEL FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

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FOREWORD

The work reported herein was done at the request of the National Aeronautics and Space Administration (NASA), Langley Research Center, Hampton, Virginia, under Program Area 921E.

The test results presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract F40600-69-C-0001. The test was conducted in the Propulsion Wind Tunnel, Supersonic (16S) on August 21 and 23, 1968, under ARO Project No. PS1897. The manuscript was submitted for publication on September 16, 1968.

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This technical report has been reviewed and is approved.

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ABSTRACT

A test was conducted in the 16-ft supersonic wind tunnel to obtain deployment, inflation, and steady-state characteristics of an inflatable decelerator attached to the base of an aeroshell entry capsule. Deployments were made at Mach numbers of 3.0 and 4.4 at free-stream dynamic pressures of 120 and 73 psfa, respectively. The preinflation method utilizing vaporization of sufficient liquid solution to completely inflate the decelerator volume resulted in successful deployments of the two decelerators. The decelerators remained fully inflated after each deployment and exhibited excellent stability.

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Illustrations

NOMENCLATURE

C_{D_D}	Drag coefficient with the AID deployed, $\frac{F_D}{q_\infty S_D}$
C_{D_u}	Drag coefficient with the AID undeployed, $\frac{F_D}{q_\infty S_u}$
F_D	Measured drag force, lb
M_∞	Free-stream Mach number
p_i	Decelerator internal pressure, psf
p_{t_∞}	Free-stream total pressure, psf
q_∞	Free-stream dynamic pressure, psf
S_D	Reference area with the AID deployed, 19.63 ft^2
S_u	Reference area with the AID undeployed, 3.14 ft^2
T_a	Temperature of aeroshell, °F
T_ℓ	Temperature of liquid solution, °F
α	Model angle of attack, deg

SECTION I
INTRODUCTION

Methods of decelerating an aeroshell entry capsule in a low surface density atmosphere are presently under investigation. Since there is an upper limit to the drag that can be obtained by aerodynamic and structural refinement of the aeroshell, there is a need for drag augmentation. At present a promising method of obtaining drag augmentation is to deploy a lightweight expandable afterbody from the aft end of an aeroshell capsule. Among the various possibilities for an expanded afterbody, inflatable pressure vessels show the most promise for a drag augmentation system with a high drag to weight ratio.

This report presents the results of tests conducted in the Propulsion Wind Tunnel, Supersonic (16S) of the Propulsion Wind Tunnel Facility, to obtain the deployment and performance characteristics of an Attached Inflatable Decelerator System (AIDS). The AID was deployed at nominal Mach numbers of 3.0 and 4.4 at nominal free-stream dynamic pressures of 120 and 73 psfa, respectively. This test was an extension of previous test work conducted in the 16S during April 1968 and reported in Ref. 1.

SECTION II
APPARATUS

2.1 TEST FACILITY

Tunnel 16S is a closed-circuit, continuous flow wind tunnel that presently can be operated at Mach numbers from 1.50 to 4.75. The tunnel can be operated over a stagnation pressure range from 200 to approximately 2300 psfa. The test section stagnation temperature can be controlled through a range of from 100 to 650°F. The tunnel specific humidity is controlled by removing tunnel air and supplying conditioned makeup air from an atmospheric dryer.

Details of the test section showing the model location and sting support arrangement are presented in Fig. 1 in the Appendix. A more extensive description of the tunnel and its operating characteristics is contained in Ref. 2.

2.2 TEST ARTICLE

The model consisted of a 120-deg conical aeroshell with a base diameter of 24 in. and an attached inflatable textile canopy that extended to a diameter of 60 in. including a 5-percent burble fence. Major model details and dimensions are shown in Fig. 2. Wind tunnel installation photographs of the aeroshell model with the decelerator stowed are shown in Fig. 3. Photographs of the model with the decelerator deployed at free-stream Mach number of 4.4 are shown in Fig. 4.

The conical aeroshell was made of aluminum alloy sheet, spun-form into final shape after an intermediate stabilizing heat treatment. A rigid, close fitting, low carbon steel tube served as the transitional support between the sting-mounted internal balance and the aeroshell.

The AID unit was constructed of Nomex® cloth and coated with Viton® (a high temperature rubber). The inflatable afterbody decelerator was designed for minimum weight by applying the concept of isotensoid design, Ref. 3. Four symmetrically located inlets permitted ram air to maintain the necessary inside pressure level after deployment. The decelerator was secured to the aeroshell by clamping the canopy end bands. The outer attachment is made to the aeroshell profile with an aluminum clamping ring, and the inner attachment is made to the balance housing with steel clamping sectors as shown in Fig. 2.

Deployment of the AID from the base of the aeroshell was accomplished by preinflation using vaporization of sufficient liquid to completely inflate the decelerator volume. A 0.5-in.-ID hose, coiled within the nose of the conical aeroshell, served as the liquid reservoir until severed at its center by a pyrotechnic cutter mechanism. The reservoir was wrapped with a strip heater to maintain the liquid at the desired temperature prior to deployment. The decelerator was restrained in its packaged configuration in the aeroshell stowage compartment by a series of loops assembled together to form a "daisy chain" hoop around the balance housing as shown in Fig. 3c. Pyrotechnic cutters were provided to sever the chain retaining cord so as to completely release the chain restraint on a given electrical signal.

2.3 INSTRUMENTATION

An internally mounted, six-component, strain-gage balance was used to measure the model forces to within ±10 lb for the range of loads measured during these tests. The decelerator internal pressure was measured with a model-mounted, 5-psid transducer. The internal

temperature of the decelerator and the liquid reservoir temperature were measured by iron-constantan (IC) thermocouples. Six motion-picture cameras and a television camera, installed in the test section walls, were used to document and monitor the test.

Outputs from the balance, pressure transducer, and thermocouples were digitized and code punched on paper tape for on-line data reduction. These inputs were also continuously recorded on direct-writing and film pack oscillographs for monitoring model dynamics.

SECTION III
PROCEDURE

The AID unit was carefully packed into the aeroshell stowage compartment before wind tunnel test operation was initiated. Once the prescribed test conditions were established, steady-state data were obtained for the undeployed configuration. A countdown procedure was used to sequence data acquisition during the AID deployment. The deployment procedure consisted of activating the recording oscillographs and test section cameras, followed by energizing an automatic sequencer system which initiated the signal to the daisy chain pyrotechnic cutters 0.23 sec before severing the liquid reservoir. Upon completion of the AID deployment sequence, steady-state loads were calculated by averaging the analog signals from the balance over a 1-sec interval.

SECTION IV
RESULTS AND DISCUSSION

Inflatable decelerator models attached to the base of an aeroshell entry capsule were deployed at free-stream Mach numbers of 3.0 and 4.4 at free-stream dynamic pressures of 120 and 73 psfa, respectively. Deployment, inflation, and steady-state data were obtained for both deployments at 0-deg angle of attack. After the deployment sequence was completed the decelerator performance was investigated over an angle-of-attack range of 0 to 10 deg at free-stream Mach numbers from 3.0 to 4.4. Data were also obtained at Mach number 2.55 for 0-deg angle of attack.

4.1 DEPLOYMENT CHARACTERISTICS

The decelerators were equipped with a method of preinflation by vaporization of sufficient liquid (6 oz, 50/50 by volume, solution of water and methyl alcohol) to completely inflate the decelerator volume upon being exposed to the low static pressure of the wind tunnel. The preinflation system is intended not only to prevent the lightweight fabric from excessive rubbing against itself during the unfolding process but also to provide for quick erection of the ram-air inlets into the air stream for immediate transfer from pressurization by self-inflation to ram-air pressurization.

The deployment-time histories of the decelerator drag loads and internal pressure rise are presented in Figs. 5 and 6. The first deployment was made at Mach number 3.0 and took approximately 0.7 sec for the decelerator to reach full inflation. This deployment time appeared to be excessive compared with the 0.25-sec deployment times experienced with the same deployment system investigated previously and reported in Ref. 1. After comparison of the two test entry models, it was found that the lightweight break-thread used in the first tunnel entry (Ref. 1) to prevent the loose folds of the stowed decelerator from flapping while tunnel test conditions were established, had been replaced with a heavier break-thread which was also attached to the decelerator in a different manner. It was felt that the heavier break-thread prevented the daisy-chain loop from completely separating and retarded the initial inflation time of the decelerator.

Before the second decelerator was deployed, part of the break-thread was replaced with a lighter thread and attached so it would not interfere with the separation of the daisy-chain loops. The decelerator was then deployed at Mach number 4.4 and as shown in Fig. 6 required approximately 0.5 sec to reach maximum steady-state drag load or full inflation. Motion picture coverage of the deployment sequence indicated that the break-thread still may have retarded the inflation of the decelerator.

The longer deployment times also resulted partly from the fact that the internal decelerator pressure rise resulting from vaporization of the liquid solution was approximately 50 percent lower than that obtained from previous deployments (Ref. 1) with the same system. This lower pressure rise is attributed to the fact that the aeroshell temperature was lower (approximately 40°F) for the two deployments presented herein compared with the deployments reported in Ref. 1. Photographs showing various stages of the two deployments are presented in Fig. 7.

4.2 STEADY-STATE CHARACTERISTICS

Steady-state drag data were obtained for the AIDS at free-stream Mach numbers from 2.55 to 4.40 and at angles of attack from 0 to 10 deg. The drag coefficients presented for the undeployed configuration are based on the aeroshell reference area, S_u, and the drag coefficients of the deployed configuration are based on the AID reference area, S_D. Photographic coverage and oscillograph traces obtained during the tests indicated that for all test conditions, including angles of attack through 10 deg, the fully inflated decelerator was very stable with no oscillating forces or moments.

The free-stream dynamic pressure was varied from 38 to 195 psfa at Mach number 3.0 with the AID deployed. The resulting drag coefficient as well as the decelerator pressure ratio (p_i/p_{t_∞}) are presented in Figs. 8 and 9, respectively. There was essentially no change in drag coefficient or pressure ratio except at the minimum dynamic pressure. This would indicate that there was little or no deformation of the inflatable afterbody over the range of dynamic pressures from 117 to 195 psfa. The data presented at a dynamic pressure of 38 psfa were obtained while attempting to unstart the wind tunnel without destroying the decelerator; the data accuracy is questionable because of the low test section pressure and high humidity. This was not intended as an established test condition, and the data are presented only to show the relatively small change in decelerator performance at the low dynamic-pressure level.

The two decelerator models were tested through the Mach number range of 2.55 to 4.40, and the drag coefficients are presented in Fig. 10 as a function of free-stream Mach number. There was less than five-percent change in the decelerator drag coefficient over the range of Mach number investigated. At a nominal free-stream Mach number of 3.0, the two data points represent the drag coefficient of two decelerators and show close agreement between the two AID models.

The drag coefficients of the aeroshell without and with the decelerator deployed are presented in Figs. 11 and 12, respectively, for angles of attack from 0 to 10 deg. An increase in angle of attack decreased the drag coefficient of both the deployed and undeployed configurations. However, the decrease in the deployed drag coefficient with angle of attack was less than two percent at all test Mach numbers, showing good decelerator performance at angles of attack through 10 deg. At Mach number 3.0 the drag coefficient data are presented for the two AID models and show close agreement at all angles of attack.

SECTION V
CONCLUDING REMARKS

Tests were conducted to investigate deployment, inflation, and steady-state characteristics of an inflatable decelerator attached to the base of an aeroshell entry capsule. Deployments were made at Mach numbers of 3.0 and 4.4 at free-stream dynamic pressures of 120 and 73 psfa, respectively. The following observations are a result of these tests:

1. Preinflation by vaporization of a liquid solution resulted in successful deployments of the two AID models with inflation times of 0.7 and 0.5 sec.
2. The AID remained fully inflated and exhibited excellent stability characteristics at Mach numbers from 2.55 to 4.40 and angles of attack through 10 deg.
3. Steady-state drag coefficient of the deployed decelerator decreased less than two percent as the angle of attack was increased to 10 deg.

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3. Houtz, N. "Optimization of Inflatable Drag Devices by Isotensoid Design." AIAA Paper No. 64-437, First Annual AIAA Meeting, Washington, D. C., June 29 through July 2, 1964.

APPENDIX
ILLUSTRATIONS

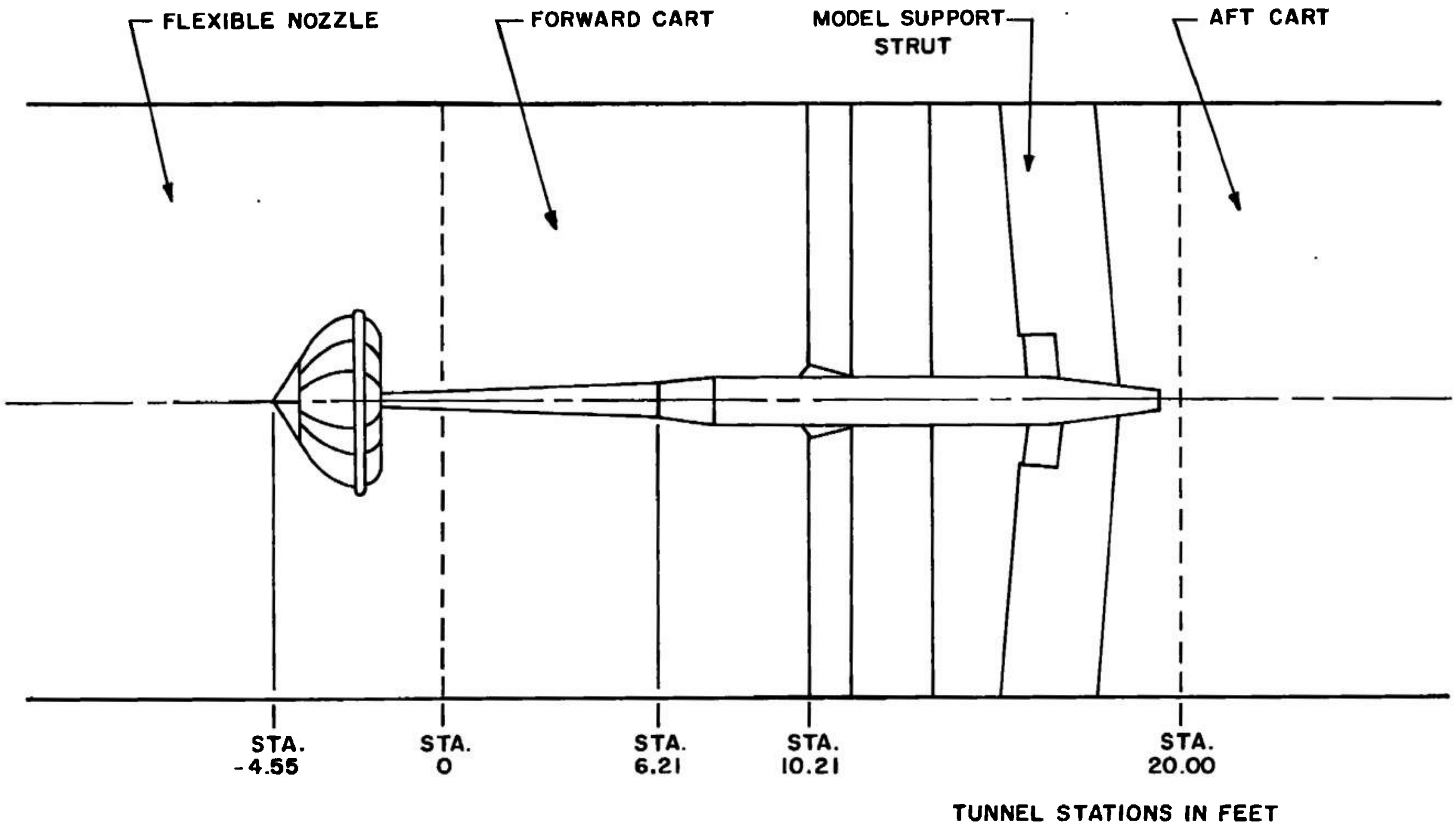
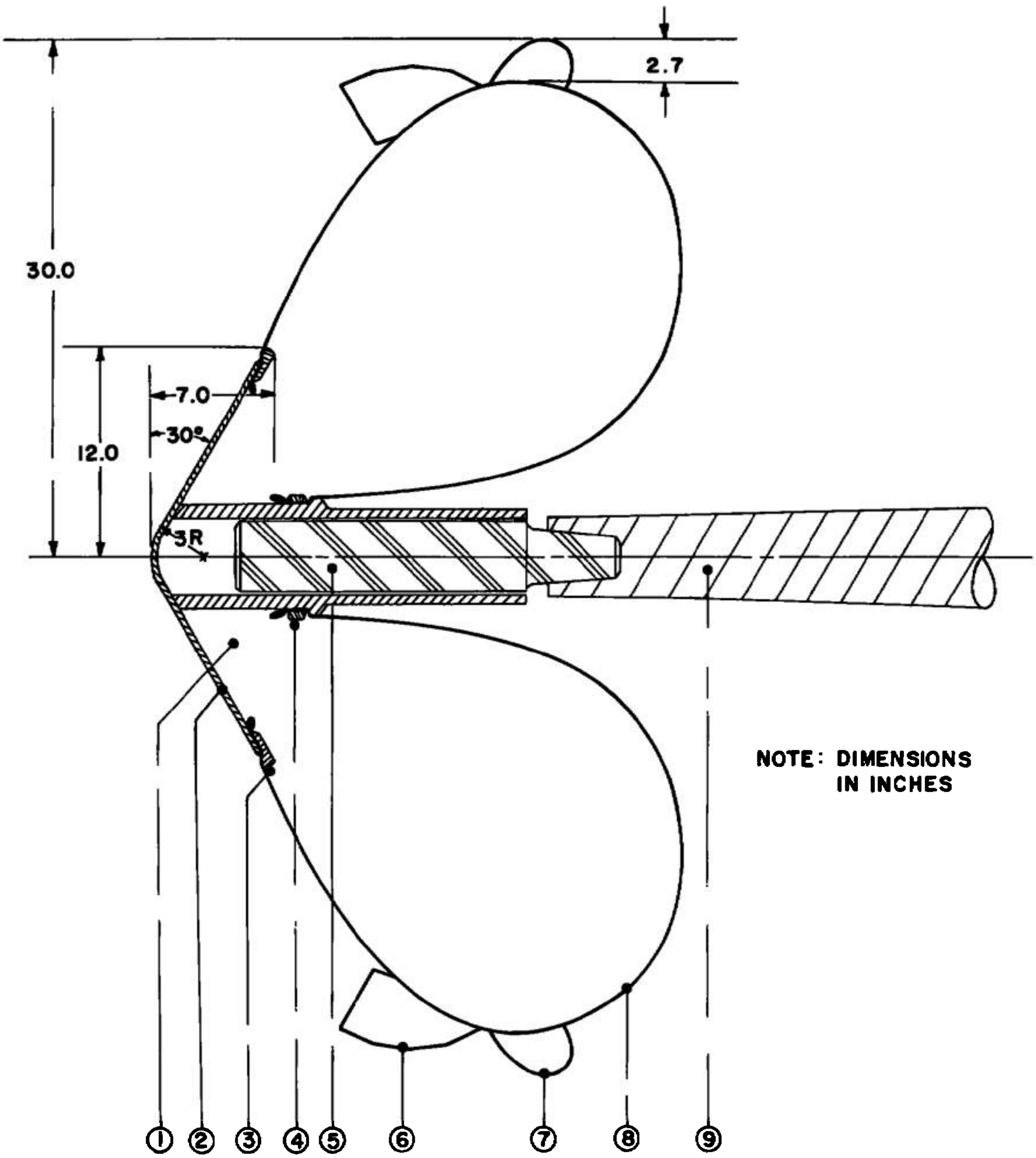
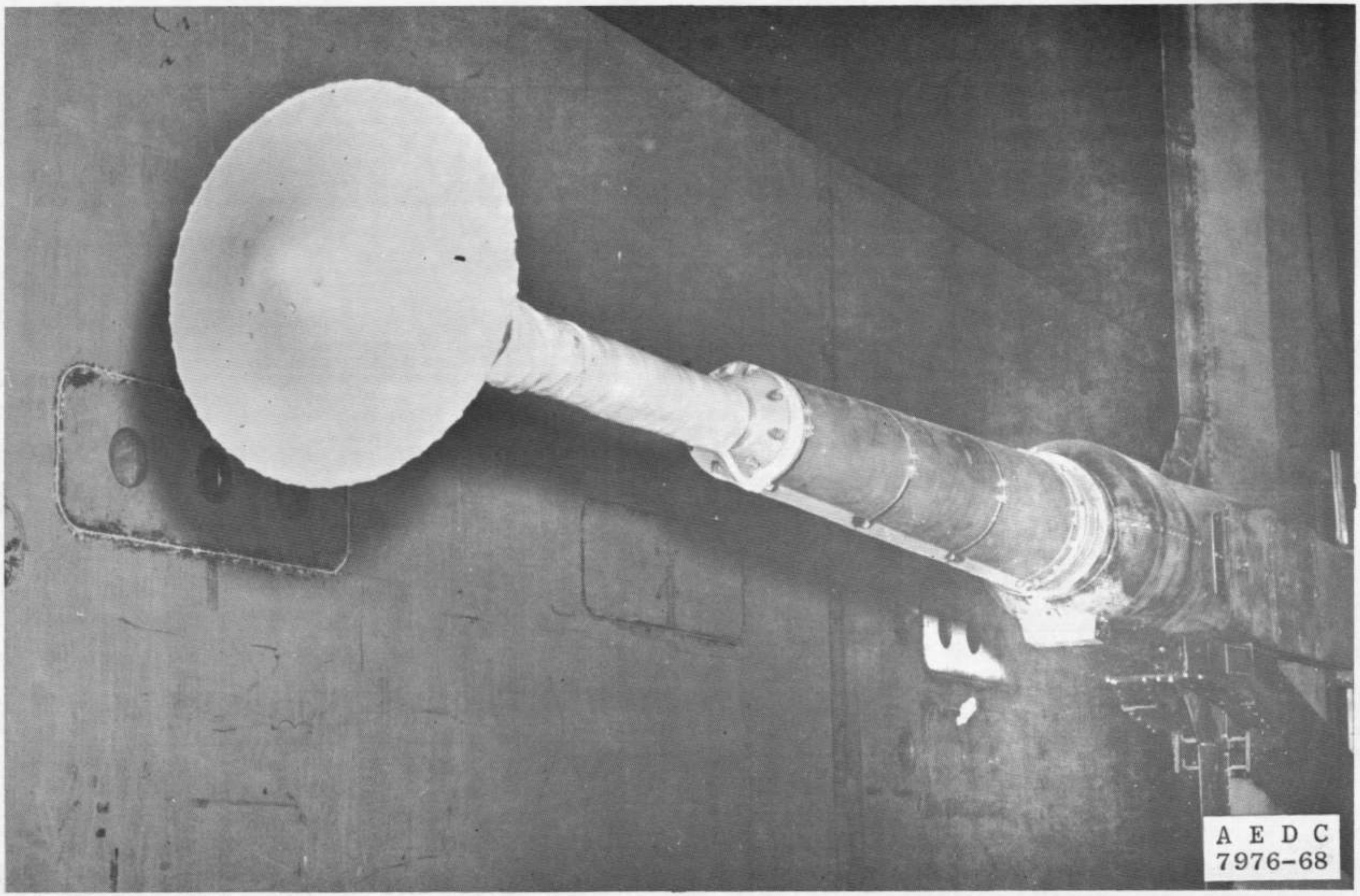


Fig. 1 Location of Model in Test Section



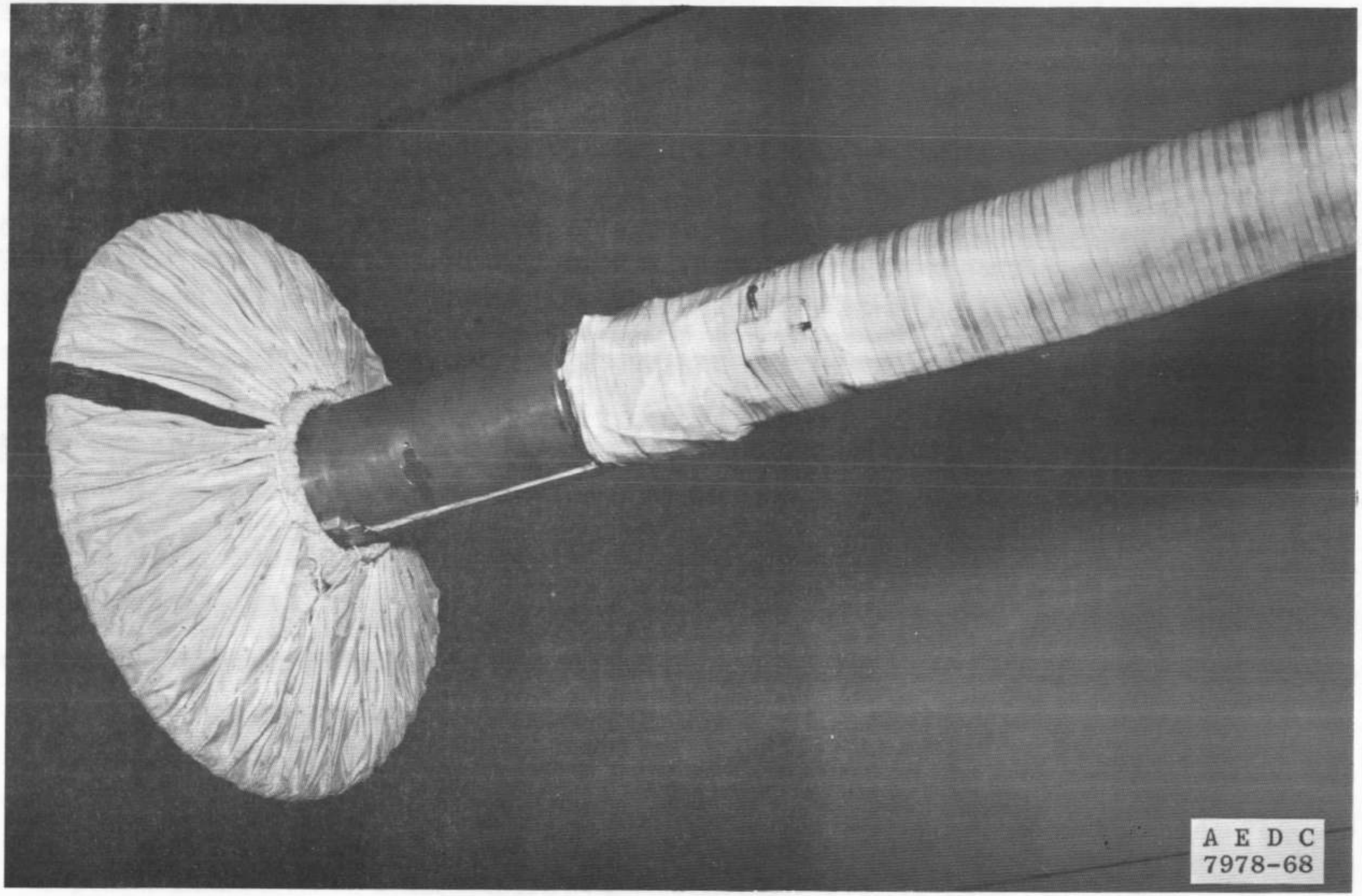
1. DECELERATOR STOWAGE COMPARTMENT
2. AEROSHELL
3. DECELERATOR CLAMP (OUTER)
4. DECELERATOR CLAMP (INNER)
5. SIX-COMPONENT BALANCE
6. DECELERATOR RAM-AIR INLETS (TYP. 4 PLACES)
7. BURBLE FENCE
8. INFLATABLE DECELERATOR
9. STING SUPPORT

Fig. 2 Details of AID Model



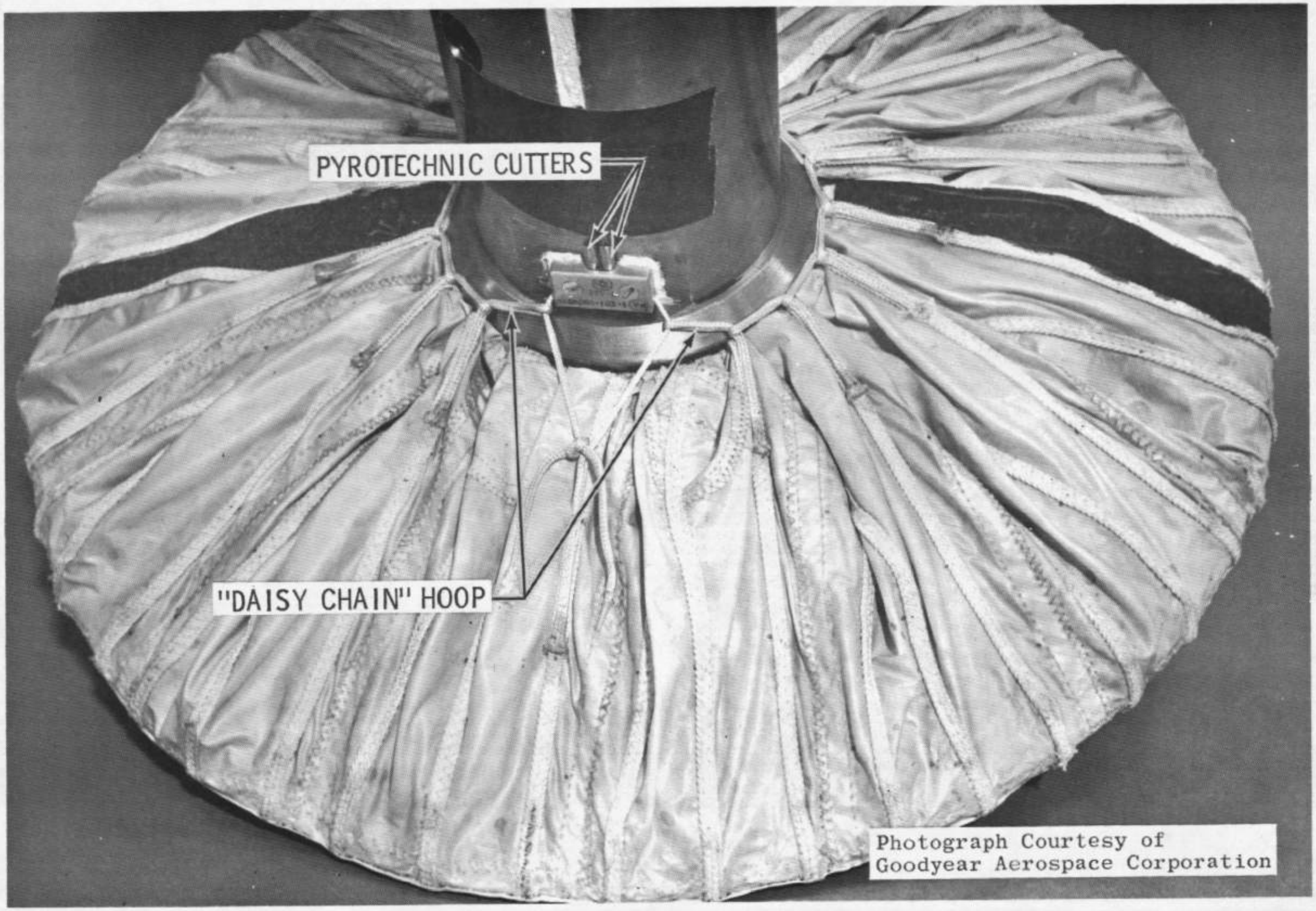
a. Front Three-Quarter View

Fig. 3 Installation of Undeployed Model in Test Section



b. Rear Three-Quarter View

Fig. 3 Continued



c. "Daisy Chain" Restraint System

Fig. 3 Concluded

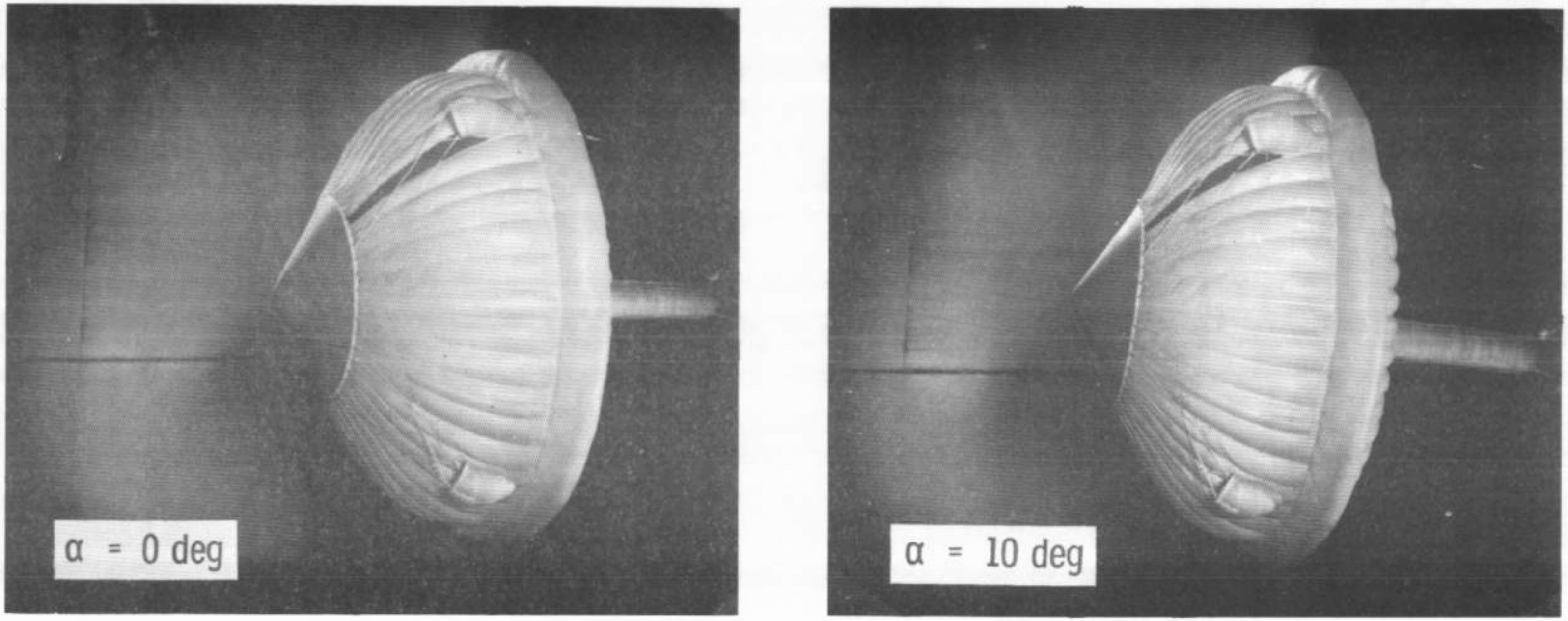


Fig. 4 AID Model at Free-Stream Mach Number 4.0, q_∞ = 110 psfa

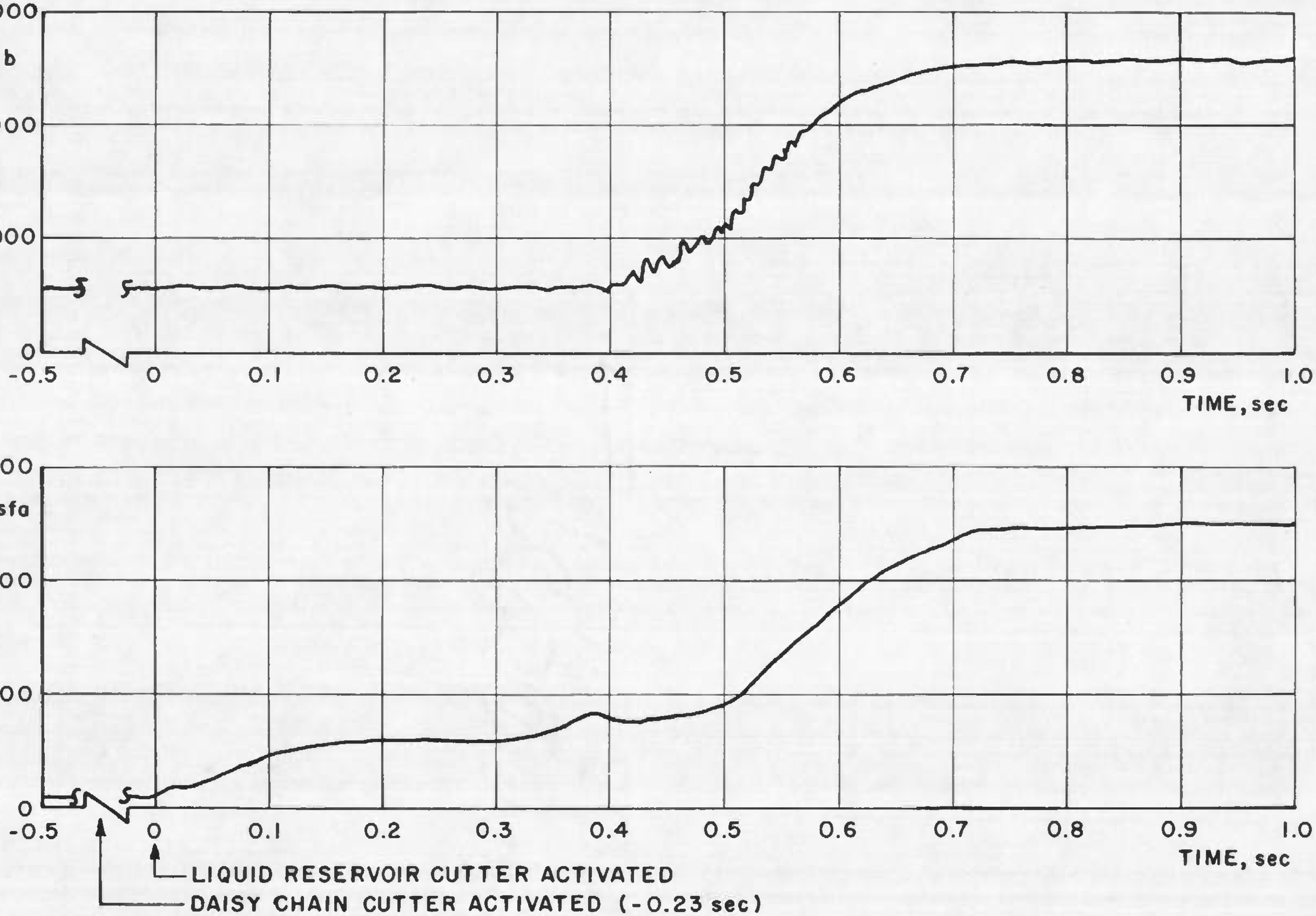


Fig. 5 Decelerator Deployment Characteristics at Mach Number 3.0, T_a = 110°F, T_ℓ = 103°F

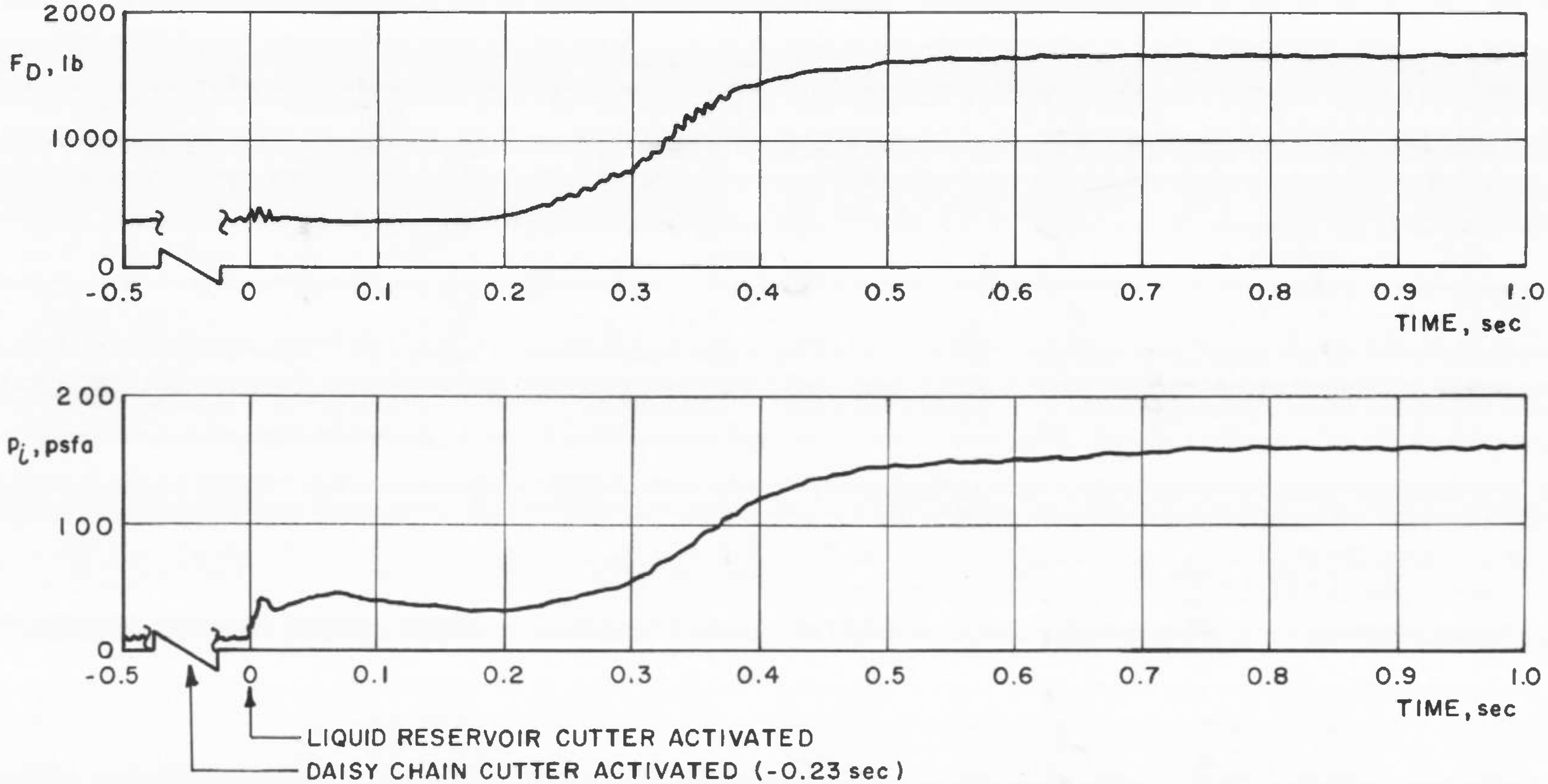
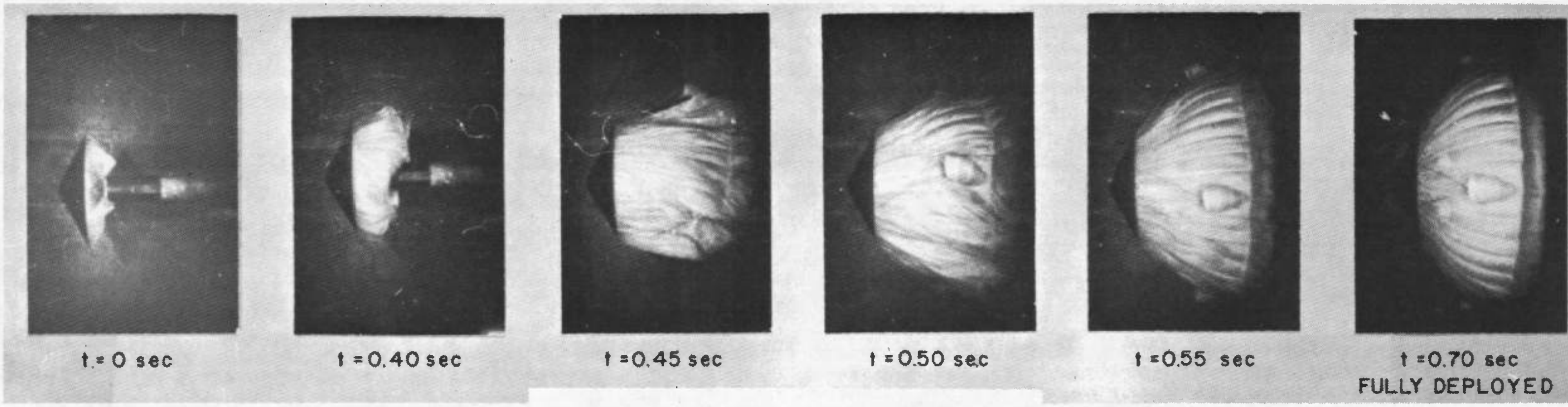
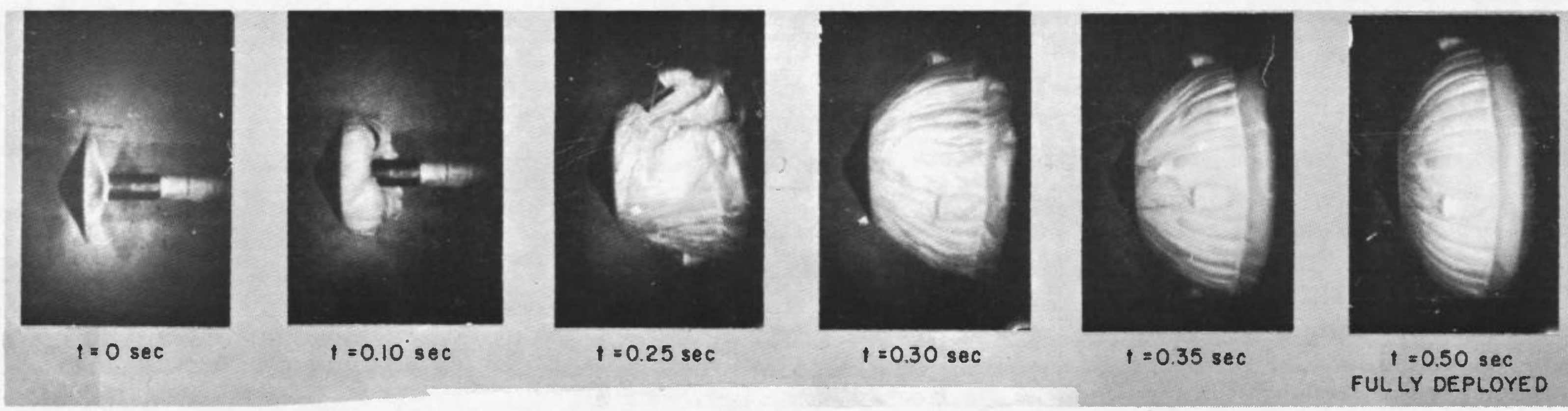


Fig. 6 Decelerator Deployment Characteristics at Mach Number 4.4, T_a = 120°F, T_l = 120°F



a. Deployment Sequence at $M_\infty = 3.0$



b. Deployment Sequence at $M_\infty = 4.4$

Fig. 7 Photographs of the Deployment Sequence

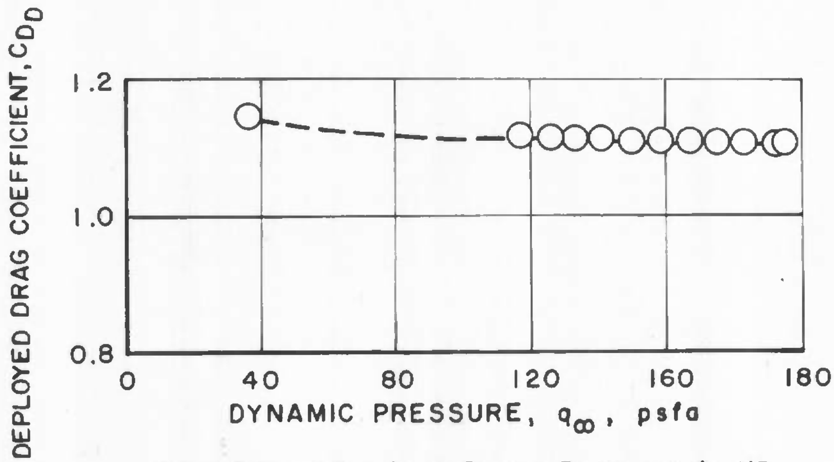


Fig. 8 Effect of Free-Stream Dynamic Pressure on the AID Drag Coefficient, M_∞ = 3.0, α = 0 deg

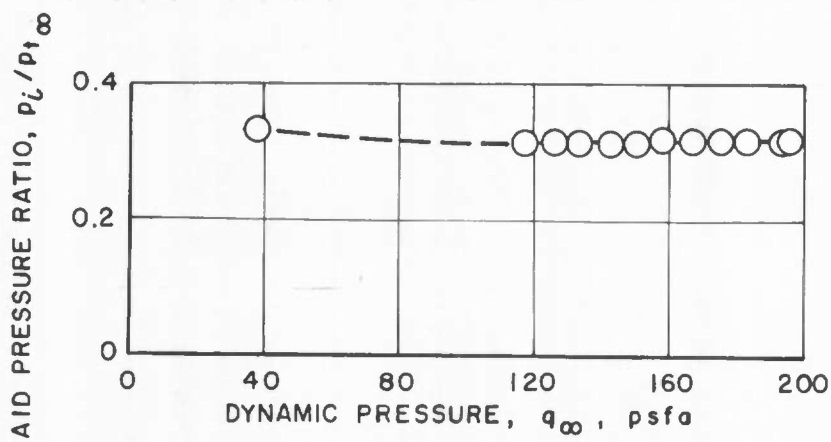


Fig. 9 Effect of Free-Stream Dynamic Pressure on the AID Pressure Ratio, M_∞ = 3.0, α = 0 deg

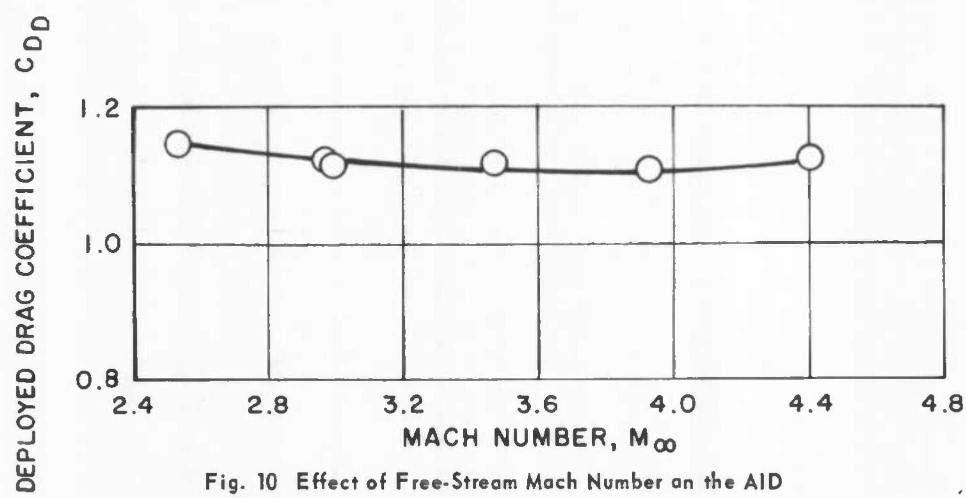


Fig. 10 Effect of Free-Stream Mach Number on the AID Drag Coefficient, α = 0 deg

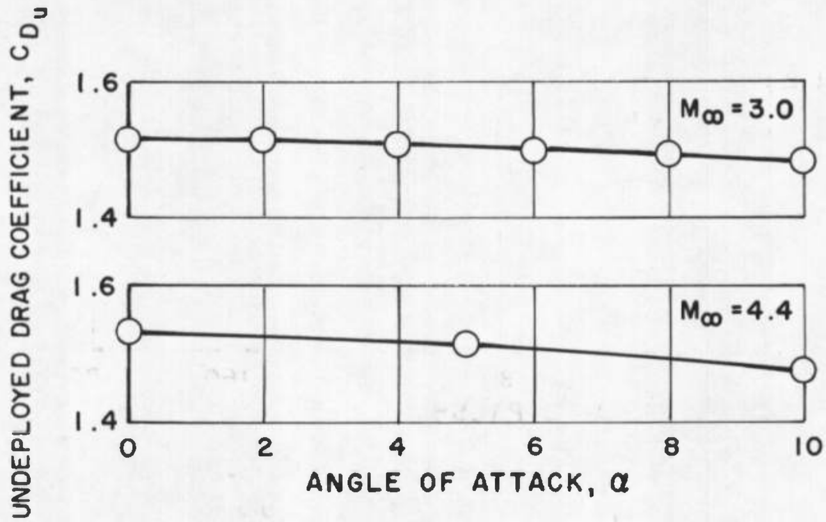


Fig. 11 Effect of Angle of Attock on Drog Coefficient with the AID Model Undeployed

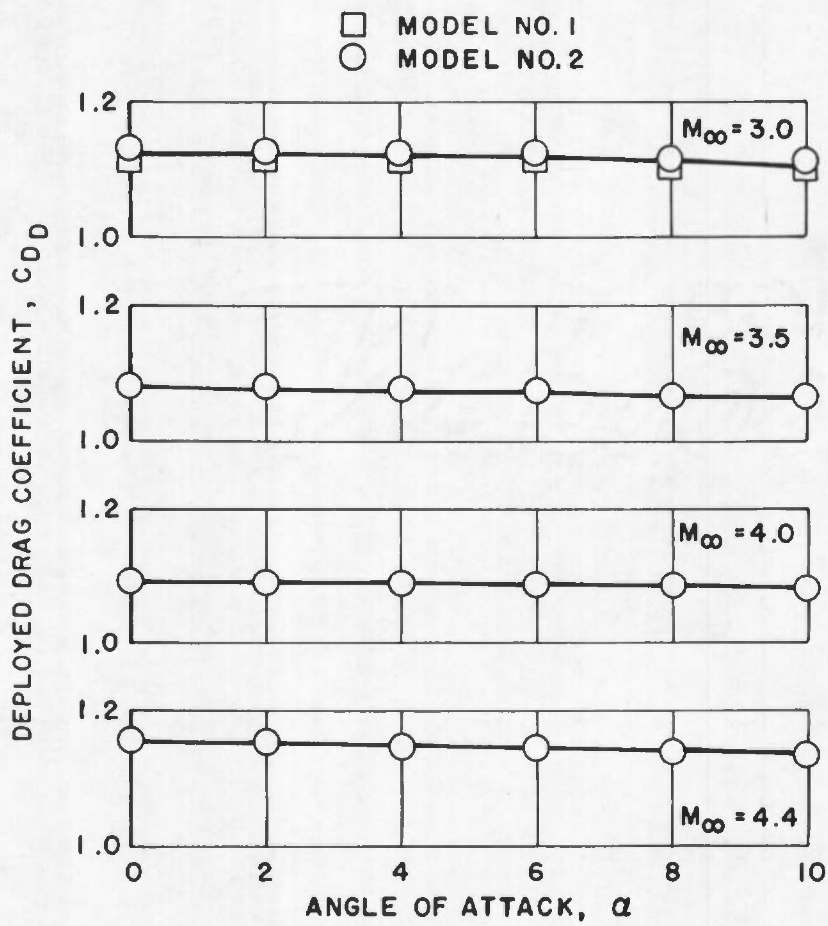


Fig. 12 Effect of Angle of Attock on Drog Coefficient with the AID Model Deployed

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13. ABSTRACT

A test was conducted in the 16-ft supersonic wind tunnel to obtain deployment, inflation, and steady-state characteristics of an inflatable decelerator attached to the base of an aeroshell entry capsule. Deployments were made at Mach numbers of 3.0 and 4.4 at free-stream dynamic pressures of 120 and 73 psfa, respectively. The preinflation method utilizing vaporization of sufficient liquid solution to completely inflate the decelerator volume resulted in successful deployments of the two decelerators. The deceleratorsremained fully inflated after each deployment and exhibited excellent stability.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
2 decelerat~~ion~~ors						
1 inflatable structures						
deployment						
supersonic flow						
atmospheric entry						
wind tunnels						

3. Reentry bodies -- Deceleration

4 Inflatable decelerators

1- 2,